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Abstract: In this paper, we study designing and managing effective dual-channel supply chain network equilibrium model to optimize the profit of each node in dual-channel supply chain network and satisfy seamlessly customer demand. The customer demand in each channel is driven by the heterogeneous consumer characteristic attributes. In our proposed model, Multinomial Logit (MNL) function is used to make a purchase decision for customers considering selling price, operation time and retail services. Furthermore, the Variational Inequality is used to express the equilibrium solution in dual-channel supply chain network. A numerical example in dual-channel supply chain network is presented to show the MNL function can be a good replacement for the demand function when customers are heterogeneous and the proposed model can be helpful to avoid time trap.

Keywords: Dual-channel supply chain network, Network Equilibrium Model, Variational Inequalities, Modified Projection Method

1. INTRODUCTION

Avoiding loss affected by "channel conflict" in dual-channel supply chain (SC) and dual-channel supply chain network (SCN) is challenging for firms who need to optimize selling price, processing time and service in dual-channel markets with heterogeneous consumer characteristic attributes. The operations of dual-channel SCN not only affect people's lives, but also the firms' profitability in SCN. Some manufacturers even have switched into single-channel SC from dual-channel SC in order to avoid this kind of channel conflict[1], while others have tried to implement differentiation strategy in dual-channel SC.

Dual-channel SC has increasingly attracted interest in recent literature. Pricing strategy in dual-channel SC is one of the key issues that previous research focus on. Considering channel control, Chiang et al.[2] construct a price-setting game between a manufacturer and its independent retailer. Chun and Kim[3] analyze the price differences between a retailer channel and a direct online channel. Chen et al.[4] examine a manufacturer's pricing strategies in a dual-channel SC and illustrate how a contract enables both the manufacturer and the retailer to be a win-win. Moreover, pricing strategies model of dual-channel SC has been developed for various characteristics and types SC, including risk management[5], retail service[6], price discounts[7], brand management[8], information sharing[9], inventory management[10], lead time management[11],[12], and quality management[13]. However, the aforementioned papers just considered the pricing issue and did not address the importance of customer choice based on the heterogeneous characteristic attributes. In our model, different choices from heterogenous customers in the characteristics of products is the driving force of forming dual-channel SC.

As noted in Nagurney et al.[14], time plays a critical role in time-sensitive products SC. Time is a fundamental element in dual-channel SC which customers care. In many papers, operation time is an significant factor that impact product quality[15],[16], waste of products[17] and lost value[18]. These studies focused on the importance of operation time in SC and the benefit followed operation time control. For the various type of products in our model, customers care different operation time combinations, including production time, delivery time and retail time in practice.

Our study builds upon earlier SCN equilibrium research and makes some new contributions. First, we develop a network equilibrium model for dual-channel SCN. On the one hand, because most of the models focused on intra-SC competition, there is little work that studies the competition among dual-channel SCs. On the other hand, competition is no longer between stand-alone companies, but rather SC against SC[19]. The strategies in a dual-channel SC were impacted by competing and cooperating SC. Second, selling prices, operation time and retail service are used as the key characteristics of products in dual-channel SCN. Consumer choices on selling price, operation time and retail service are driven by the consumer characteristic attributes. By accounting for consumer-driven time and service competition, we can address a deeper understanding of time and service competition in dual-channel SCN, which allows managers to evaluate the time and service competition decision from consumer’s perspective in dual-channel SCN and implement a discrete choice model to support their decentralized decisions. Next, ignoring consumers’ preferences and needs, Stalk and Webber[20] reported many firms found themselves caught in a time trap. MNL function, as a discrete choice model, is developed to understand consumer purchase decisions among selling price, operation time and retail service based on the consumer characteristic attributes in dual-channel SCN. Finally, shoes were used as a representative example in dual-channel SCN.

2. DUAL-CHANNEL SCN EQUILIBRIUM MODEL

In this section, we develop a dual-channel SC network equilibrium model for manufacturers, retailers and customers in markets including the costs associated with the production, transportation, marketing, storage, and retail service. The decision-makers in the SCN, specifically the manufacturers and retailers, are assumed to seek profit maximization considering the operation time and retail service. In view of consumer characteristic attributes among price time and retail service, the consumers in the market make their own decisions in accordance with their preference and utility. A typical dual-channel SC structure is shown in Figure 1.

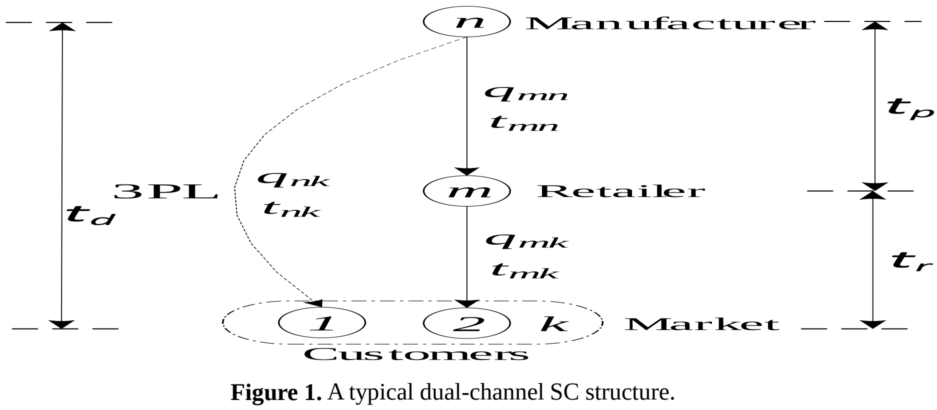

Figure 1. A typical dual-channel SC structure.

More than two dual-channel SCs form a dual-channel SCN. We designate N product manufacturers, a typical manufacturer is called n who transports its products to K demand markets by direct channel, a typical market is called k (Figure 2). In the traditional channel, manufacturer n will sell and delivery part of products to retailer m at first. Then, retailer m will sell the products to demand markets in the end and provide additional retail service for customers using traditional channel. In this scenario, according to consumer preference between selling price, time and retail service, there are two options for consumers to select: direct channel and traditional channel.

Consider a general network with time attribute $H=[G,L,T]$, where G denotes the set of nodes in the network, L denotes the set of directed links and T denotes the set of operation time on directed links. The links between node n and node m can be production and transaction from manufacturer n to retailer m. The links between node m and node k can be the transaction from retailer m to market k. The links between node n and node k can be the production and transaction from manufacturer n to market k by direct channel or 3PL service.

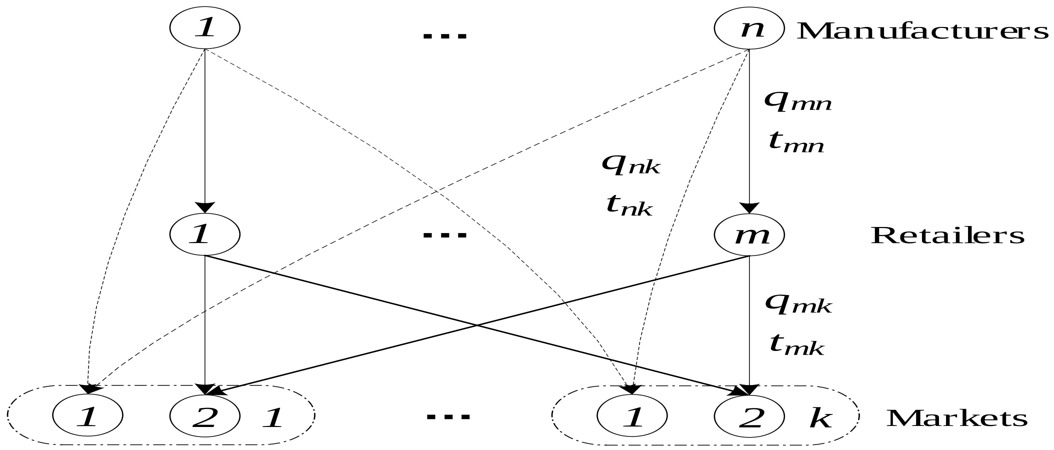

Figure 2. A typical dual-channel SCN structure.

In this paper, we assume the process of production, transportation and marketing is assumed to be acyclic. We suppose that the firms in SC compete and cooperate in a selling season. Different from the definition of a general operation time on links directly, similar to that in[21], we divide the operation time in dual-channel SC into 3 types, (t_{nm},t_{mk},t_{nk}) according to customer preference and product characteristics. The operation time (t_{nm}) between manufacturers and retailers includes production time, storage time and delivery time so on. The operation time (t_{mk}) between retailers and demand markets includes storage time and delivery time so on. The operation time (t_{nk}) between manufacturers and demand markets includes production time, storage time and delivery time so on. Operation time in dual-channel SC is a key factor that customers care. For example, In a fashion clothing or a book dual-channel SCN, customers balance between t_{nk} and t_{mk}. In a customized products dual-channel SCN, customers trade-off between t_{nk} and $t_{nm}+t_{mk}$. Usually the operation time T between a manufacturer and a marketplace is easy for consumers to get from the external packing of part products in supermarkets or to percept after making an order.

Definition I: The variational inequality problem

The variational inequality problem. *The finite-dimensional variational inequality problem,* $VIP(U,K)$*, is to determine a vector,* $x^*\in\Omega\subset R^n$*, such that*

$$\langle \nabla U_s(X^*),(X_s-X_s^*)\rangle\geq 0,\forall X\in\Omega. \tag{1}$$

Where $\Omega=\left\{x_{a_{ij}}\geq 0,p_{ij}\geq 0: N_k\cdot Pr_j(\vec{V}_j)=\sum_{s\in S}x_{s_{ij}}\right\}$ *is the feasible set of chain variables for the SCN in our model.* U *is a given continuous function from* K *to* R^n*,* K *is a given closed convex set, and* $\langle\cdot,\cdot\rangle$ *denotes the inner product in n dimensional Euclidean space.* X^* *is a network economic equilibrium if and only if* X^* *satisfies (1)*[22].

2.1 The equilibrium conditions for manufacturers

The transaction between manufacturer n and retailer m is a solid arrow line in Fig. 2. The transaction between manufacturer n and demand market k is denoted by dotted arrow lines in Fig. 2. The production output of manufacturer n satisfies the conservation of product flow equation (2). The production output of manufacturer n is equal to the sum of the quantities sent from manufacturer n to all retailers and all customers through all delivery methods. Here we assume that each manufacturer has a production cost function f_n.

$$Q_n = \sum_{m=1}^{M} q_{nm} + \sum_{k=1}^{K} q_{nk} \tag{2}$$

$$f_n = f_n(Q_n),\ \forall n. \tag{3}$$

The transaction cost between manufacturer n and retailer m, as well as the transaction cost between manufacturer n and consumers in market k, include the transportation cost and insurance cost which depends on the volume of product flow between the two nodes. The transaction costs are given by:

$$c_n = c_{nm}(q_{nm}) + c_{nk}(q_{nk}), \forall n, m, k. \tag{4}$$

The operation time t_{nm} between manufacturer n and retailer m, including production time and transportation time are related to the relevant transaction cost. In our model, manufacturer n provides w operation time options associated with different cost functions.

$$t_{nm} \longrightarrow c_{nm}, \forall n, m. \tag{5}$$

Every manufacturer goes for profit maximization. So, the profit of manufacturer n is equal to the price p_{nm}^1 that manufacturer n charges for the product multiplied by the volume of product shipping to all retailers, with the addition of the price p_{nk}^1 that manufacturer n charges for the products multiplied by the volume of product shipping to all consumers in markets, minus the production cost and transaction cost. The function of profit maximization for manufacturer n can be expressed as:

$$max \sum_{m=1}^{M} p_{nm}^1 \cdot q_{nm} + \sum_{k=1}^{K} p_{nk}^1 \cdot q_{nk} - f_n(Q_n) - \sum_{m=1}^{M} c_{nm}(q_{nm}) - \sum_{m=1}^{M} c_{nk}(q_{nk}) \tag{6}$$

$$s.t.\, q_{nm} \geq 0, q_{nm} \geq 0; \forall n, m, k. \tag{7}$$

2.2 The equilibrium conditions for retailers

The transaction cost between retailer m and customers in market k may include transportation, display, and storage costs associated with these products. There is only a delivery way between retailers and customers in markets, which is a solid arrow line in Figure 2. Let c_{mk} and c_{mk}^s respectively denote a transaction cost function and retail service cost between retailers m and customers in market k. c_{mk} is a function of q_{mk} and c_{mk}^s is a function of retail service s_{mk}. The transaction cost function and retail service cost function, then, can be expressed as:

$$c_{mk} = c_{mk}(q_{mk}), \forall m, k. \tag{8}$$

$$c_{mk}^s = c_{mk}^s(s_{mk}), \forall m, k. \tag{9}$$

The operation time t_{mk} between retailers m and customers in market k is related to the relevant transaction cost, too. Assuming that every retailer is a profit-maximizer, the profit of retailer m is equal to the price p_{mk}^2 that retailer m charges for the products multiplied by the volume of the products shipping to all customers, minus the transaction cost and retail service cost. The function of profit maximization for retailer m can be expressed as:

$$max \sum_{k=1}^{K} p_{mk}^2 \cdot q_{mk} - \sum_{k=1}^{K} c_{mk}(q_{mk}) - \sum_{k=1}^{K} c_{mk}^s(s_{mk}) - \sum_{n=1}^{N} p_{nm}^1 \cdot q_{nm} \tag{10}$$

$$s.t. \sum_{n=1}^{N} q_{nm} \geq \sum_{k=1}^{K} q_{mk}, \forall n, m, k. \tag{11}$$

2.3 The behavior of consumers in markets

Suppose that there are j products in dual-channel SCN. Let p_k^{2j} denote the price of product j on market k. We assume that the prices of all market K are transparent for all consumers, because the Internet has changed the way to obtain price information[23]. In point of price, the consumers take the price charged by a retailer p_k^2, or the price charged by a manufacturer p_k^1, into consideration. The price will not exceed the price that the consumers in markets are willing to pay for the product. The equilibrium conditions in markets take the following forms:

For all manufacturers $n; n = 1,2,\cdots,N$:

$$\left.\begin{array}{l} p_k^{1j*} \leq \xi_k^{2j*}, if \quad q_{nk}^{j*} > 0 \\ p_k^{1j*} > \xi_k^{2j*}, if \quad q_{nk}^{j*} = 0 \end{array}\right\} \tag{12a}$$

For all retailers $m; m = 1,2,\cdots,M$:

$$\left.\begin{array}{l} p_k^{2j*} \leq \xi_k^{2j*}, if \quad q_{mk}^{j*} > 0 \\ p_k^{2j*} > \xi_k^{2j*}, if \quad q_{mk}^{j*} = 0 \end{array}\right\} \tag{12b}$$

Customers in our model are assumed to be heterogeneous. Some consumers care more about operation time or retail service of goods than price, others vice versa. Suppose that customers are statistically identical and independent. In our study, we view the same product with distinctive characteristics attribute as variants. Let Pr_{ij} denote the probability of the consumers choosing variant $i: i = 1,\cdots,I$. The utility function that customers choose variant i is a linear random utility model (LRUM)[24].

$$U_j(i) = \vec{\emptyset}_j \cdot \vec{V}_j + \varepsilon_j, \forall i,j \in J. \tag{13}$$

Where $\vec{V}_j(i)$ is the product's characteristics attributes vector, including consumer's valuation, selling price, operation time and retail service of variant, denoted respectively by C,P,T,S. In this expression $\varepsilon_{j,w}$ is called idiosyncratic taste differences of consumers and uncertainty which cannot be observed. $\varepsilon_{j,w}$ are *i.i.d.* and follow a double exponential distribution with mean zero. The exponential, the double exponential and the Gumbel distributions were verified well to satisfy the requirements[25],[26].

Let $\vec{\emptyset}_j(\alpha,\beta,\gamma)$ denote the customer's sensitivity coefficients that are nonnegative absolutely continuous random variables expressing the consumer's preference[24], including price sensitivity coefficient, time sensitivity coefficient and retail service sensitivity coefficient computed by using maximum-likelihood estimation (MLE), respectively. The probability of choosing alternative (i,j) out of a total alternative of is:

$$Pr_{ij}(\vec{V}_j) = \frac{e^{(U_j(i))}}{1+\sum_{i=1}^{I} e^{(U_j(i))}}, i = 1,\cdots,I; j = 1,\cdots,J. \tag{14}$$

The probability of a consumer rejecting all variants options is $1 - Pr_{ij}(\vec{V}_j)$. If $\vec{\emptyset}_j$ are estimated according to customer choices in i variants, the likelihood $(\mathcal{L})$ is given as

$$\mathcal{L}(\vec{\emptyset}_j) = \left[1 - \sum_{i=1}^{I} Pr_{ij}(\vec{V}_j)\right]^{N_0} \prod_{i=1}^{I} Pr_{ij}(\vec{V}_j)^{N_i}, \tag{15}$$

Then we solve the optimal $\vec{\emptyset}_j$ for $j \in [1,\cdots,J]$ which maximizes $\ln \mathcal{L}(\vec{\emptyset}_j)$.

If the equilibrium price the consumers are willing to pay is positive, the shipments from retailers and manufacturers must be equal to the demand for the products of consumers.

$$N_k \cdot Pr_j(\vec{V}_j) \begin{cases} = \sum_{m=1}^{M} q_{mk}^* + \sum_{n=1}^{N} q_{nk}^*, if\ \xi_k^{2(j)*} > 0 \\ < \sum_{m=1}^{M} q_{mk}^* + \sum_{n=1}^{N} q_{nk}^*, if\ \xi_k^{2(j)*} = 0 \end{cases} \tag{16}$$

2.4 The equilibrium conditions of the dual-channel SCN

The manufacturers and retailers are assumed to compete in a noncooperative fashion. It is also assumed that the production cost functions and the transaction cost functions for each manufacturer and retailer are continuous and convex. The optimization function (6) for all manufacturers, the optimization function (10) subject to (11) for all retailers and functions (12), (16) can be expressed as the following variational inequality[26],[28]-[31].[29],[30],[31].

$$\sum_{n=1}^{N}\left[\frac{\partial f_n(q_n^*)}{\partial q_n}\right]\times[q_n-q_n^*]+\sum_{n=1}^{N}\sum_{m=1}^{M}\left[\frac{\partial c_{nm}(q_{nm}^*)}{\partial q_{nm}}-\xi_m^1\right]\times[q_{nm}-q_{nm}^*]+\sum_{n=1}^{N}\sum_{k=1}^{K}\left[\frac{\partial c_{nk}(q_{nk}^*)}{\partial q_{nk}}-\xi_k^2\right]\times[q_{nk}-q_{nk}^*]+\sum_{m=1}^{M}\sum_{k=1}^{K}\left[\frac{\partial c_{mk}(q_{mk}^*)}{\partial q_{mk}}+\xi_m^1-\xi_k^2\right]\times[q_{mk}-q_{mk}^*]+\sum_{m=1}^{M}\sum_{k=1}^{K}\left[\frac{\partial c_{mk}^s(s_{mk}^*)}{\partial s_{mk}}\right]\times[s_{mk}-s_{mk}^*]+\sum_{m=1}^{M}\left[\sum_{k=1}^{K}q_{mk}-\sum_{n=1}^{N}q_{nm}\right]\times[\xi_m^1-\xi_m^{1*}]+\sum_{k=1}^{K}\left[\sum_{m=1}^{M}q_{mk}-N_k\cdot Pr_j(\vec{V}_j)\right]\times[\xi_k^2-\xi_k^{2*}]+\sum_{k=1}^{K}\left[\sum_{n=1}^{N}q_{nk}-N_k\cdot Pr_j(\vec{V}_j)\right]\times[\xi_k^2-\xi_k^{2*}]\geq 0 \qquad \forall q,\xi^1,\xi^2\in R_+^{NM+MK+NKJ}. \tag{17}$$

The term ξ_m^1 is the Lagrange multiplier associated with constraint (11) for retailer m. The term ξ_k^2 is the Lagrange multiplier for customers in market k. The production quantity and shipments that the manufacturers send to the retailers must be equal to the production quantity and shipments that the retailers accept from the manufacturers. The amount of product purchased by the customers must be equal to the shipments that the customers accept from the retailers and manufacturers. We state the equilibrium conditions of the whole dual-channel SCN as a variational inequality formulation.

3. ALGORITHM AND NUMERICAL EXAMPLE

In this section, the algorithm that we use for the computation of the product equilibrium pattern satisfying variational inequality (17) is the Projection Method[32],[31]. Then we present one example of dual-channel SCN in disparate geographic areas, specifically, SCN for shoes.

The example is developed for shoes dual-channel SCN. There are two retailers in two markets who purchase shoes shipped from two manufacturers. Two manufacturers ship shoes to these retailers and customers in two demand markets, in which the populations are $N_1 = N_2$ =10000, respectively (Figure 3). The two manufacturers are designed to offer two different strategies to satisfy heterogeneous customers with different requirements: online direct channel and traditional retail channel.

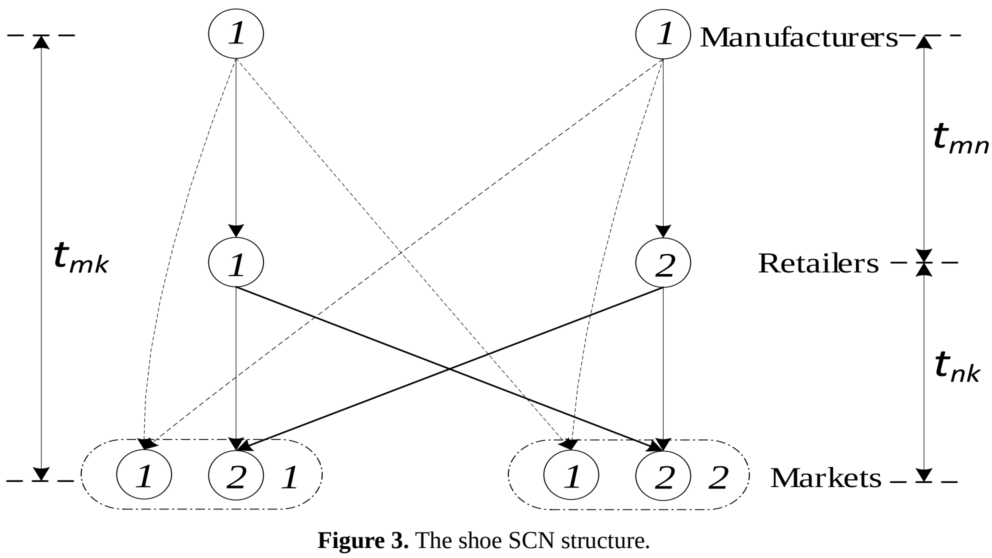

Figure 3. The shoe SCN structure.

The relative data of example are given in table 1. The retailer service cost function is given: $c_{mk}^s =$

$\frac{1}{2}\eta s_{mk}^2, \forall m, k$[33]. The algorithm is implemented in MATLAB R2017a (step length $\rho = 0.001$, convergence precision $\varepsilon = 0.002$, $\eta = 0.5$).

Table 1. Cost functions and time required in this shoes dual-channel SCN.

SC 1		SC 2	
Time	Cost	Time	Cost
$t_{p_1} = 2$	$f_1 = 4q_1$	$t_{p_2} = 2$	$f_2 = 4q_2$
$t_{d_{11}} = 2.5$	$c_{nk} = 2q_{nk} + 1$	$t_{d_{21}} = 2.5$	$c_{nk} = 2.5q_{nk} + 1$
$t_{d_{12}} = 3$	$c_{nk} = 2q_{nk} + 1$	$t_{d_{22}} = 3$	$c_{nk} = 2.5q_{nk} + 1$
$t_{r_{11}} = 1$	$c_{mk} = 3q_{mk}$	$t_{r_{21}} = 1$	$c_{mk} = 3q_{mk} + 1$
$t_{r_{12}} = 1$	$c_{mk} = 3q_{mk} + 1$	$t_{r_{22}} = 1$	$c_{mk} = 3q_{mk}$

Considering 2 different cases, we respectively generate the sales record of 400 heterogeneous customers to estimate the consumer's valuation, C_{ij}, price sensitivity coefficient α_{ij}, time sensitivity coefficient β_{ij} and retail service sensitivity coefficient γ_{ij} for each demand market. We test 2 cases where the customers are heterogeneous follow the under distributions. Each case has a special consumer's valuation, or high price sensitivity or high retail service sensitivity.

Case 1: The customers are heterogeneous in α, β and γ, i.e., $C = 1$, $\alpha = N(0.07, 0.002^2)$, $\beta = N(0.05, 0.001^2)$ and $\gamma = N(0.05, 0.001^2)$.

Case 2: The customers are heterogeneous in α, β and γ, i.e., $C = \mathcal{U}(0.9, 1.1)$, $\alpha = N(0.05, 0.002^2)$, $\beta = N(0.05, 0.001^2)$ and $\gamma = N(0.07, 0.001^2)$.

These two cases are used to simulate the implement of our dual-channel network equilibrium model when the firms face heterogeneous customers in practice. At first, we use the method introduced in section 2.3 to estimate consumer's valuation, price sensitivity coefficient, time sensitivity coefficient and retail service sensitivity coefficient. The coefficients that we estimated using MLE are shown in table 2. Then, we use the coefficients in table 2 to compute the equilibrium flow and price for each case.

Table 2. $\vec{\emptyset}$ estimated by MLE with MNL.

Coefficient	**Demand market**	$\boldsymbol{C}$	$\boldsymbol{\alpha}$	$\boldsymbol{\beta}$	$\boldsymbol{\gamma}$
Case 1	1	0.9892	0.0516	0.0494	0.0494
	2	0.9876	0.0513	0.0482	0.0482
Case 2	1	0.9779	0.0534	0.0479	0.0679
	2	0.9859	0.0524	0.0492	0.0692

For the network and cost structure of the shoes dual-channel SCN given above, assume that the utility function at markets, $U = C - \alpha P - \beta(t_{mk} \text{ and } t_{nk}) + \gamma S + \varepsilon$. Then, the equilibrium is computed in table 3.

Table 3. Computed equilibrium values on links ($\rho = 0.001$, $\varepsilon = 0.0001$).

Results	q_{nm}		q_{mk}				q_{nk}				p				s			
	q_{11}	q_{22}	q_{11}	q_{12}	q_{21}	q_{22}	q_{11}	q_{12}	q_{21}	q_{22}	p_{11}	p_{12}	p_{21}	p_{22}	s_{11}	s_{12}	s_{21}	s_{22}
Case 1	5522.0	6482.6	2015.8	576.5	1055.3	2356.2	1464.8	1464.8	1535.5	1535.5	24.0	24.7	24.2	24.9	39	39	39	39
Case 2	5346.1	6655.6	2188.2	224.0	878.7	2710.0	1467.0	1467.0	1533.4	1533.4	35.8	36.9	36.7	37.8	42	42	42	42

4. CONCLUSIONS

Dual-channel SCN is facing many problems such as low logistics efficiency, long transportation time and channel conflict. All these problems are required to be solved by a systematic and intelligent network [34]. The tool and method of designing and managing effective dual-channel SCN would be beneficial to firms and consumers in dual-channel SCN. In this paper, a dual-channel SCN equilibrium model with customer-driven was developed considering heterogeneous consumer characteristic attributes, which is comprised of multiple product manufacturers, retailers and customers in competing markets. We began by considering operation time on links associated with different transaction cost and retail service. Next, a discrete choice model was designed to illustrate the customer choice from consumer-driven perspective in competing markets where the consumers make decisions among selling price, operation time and retail service according to their characteristic attributes. Furthermore, a finite-dimensional variational inequality was adopted to formulate the dual-channel SCN equilibrium conditions. Finally, a numerical example was provided to illustrate the model and the computational procedure.

5. ACKNOWLEDGEMENTS

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